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Locating New Coal-fired Power Plants with Carbon Capture Ready Design – A GIS Case Study of Guangdong Province in China

Jia Li[a], Tim Cockerill[b], Xi Liang[c], Jon Gibbins[d]1*

[a] *Mechanical Engineering Department, Imperial College London*
[b] *Centre for Environmental Policy, Imperial College London*
[c] *Judge Business School, University of Cambridge*
[d] *Judge Business School, University of Cambridge*

Abstract

Making new coal-fired power plants carbon capture ready (Carbon Capture Ready) in China has been recognised as a crucial by a number of stakeholders academics, energy companies and regional government, based on a study in EU-UK-China NZEC project [1]. A number of publications have investigated the definition, engineering requirements, economic and finance of CCR for China. However there remain a number of questions regarding the extent to which a plant's physical location might constrain the feasibility of CCS retrofit. To address this issue, a Geographical Information System (GIS) has been used as a tool for mapping current and planned large carbon dioxide sources in Guangdong, also illustrating potential storage sites and calculating possible carbon dioxide transportation route.

This paper investigates the location factors that should be considered when locating new build CCR power plants and demonstrates the methodology of using GIS software with spatial analysis in planning new build power plant in Guangdong. A preliminary study has identified over 30 large power plants within the region, with plant locations and historical emission data collected and presented in ArcGIS. Factors such as distance to potential storage site, route of CO_2 pipeline, extra space on site and potential development plan etc. were investigated in the modelling and calculated the potential source and sink solution. The study then moves on to suggest possible new build plant locations which can be easily fitted in to the current network, based on economic optimisation. The scope for future coal plant development combined with a possible nuclear plant siting plan is discussed towards the end of the paper.

Guangdong province, which owns the third largest coal-fired power installed capacity out of 31 provinces, generated over 8% of China's total electricity every year for the past 15 years. CO_2 storage opportunities could be found in the surrounding South China Sea, where Guangdong has a total of 4,300 km of coastline and some small scale oil fields on shore within the region. It is also among the first places to start the national open and reform policy in China. The province is one of the richest in China, with the highest GDP among all other provinces since 1989, and the foreign trade accounts for more than a quarter of China's total amount. It also contributes around 12% of the total national economic output. Currently, the provincial government is proposing a low carbon roadmap, which is the first of its kind in China.

The work has created a totally new thinking on capture ready power plant planning. This differs from existing studies (e.g. [2], [3], [4]), which aim to investigate the existing carbon dioxide emission sources at specified location and provide source and sink matching analysis. Instead the study focuses on policy implementation for new build capture ready power plants. Three clusters within Guangdong province are identified as potential temporary CO_2 storage hubs before transporting the gas to a long term storage site. When officials are planning new power plant locations from a capture ready perspective, the plants should not necessarily be close to storage sites in straight line, but rather should be within a reasonable distance of a cluster. Transport of the captured CO_2 will not be limited to pipelines, but could be extended to road and rail tankers.

Power plant parameters and storage site data were collected for this research. Public transportation, utilities, landscapes, river, land used and population data were referenced from various sources; therefore, some of the data could

* Jia Li. Tel.: +44-785-333-7662.
E-mail address: j.li05@imperial.ac.uk.

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be out of date. Nevertheless, it should still provide enough information when deciding the location of the transport cluster. Any future work could build on the existing model with updated data. Moreover, it could fit in with the national natural gas transportation network and utility planning network to provide long term integrated energy system analysis.

The paper could provide policy makers, investors and urban planning officials with a view on how conventional thermal power plant investment and planning could be optimised, using Carbon Capture Ready designs, to keep the CCS retrofitting option open.

Keywords: CCS ready; capture ready; GIS analysis;

1. Regional carbon capture ready planning

The criteria for site selection for capture ready fossil power plants include site specifications, such as engineering, legislation, geological and external factors, accessibility of the site by pipeline, proximity to coal resources, availability of industrial infrastructure and technical support, plus many other economic, social and environmental factors. Such criteria, however, vary from country to country, from region to region, depending on the prevailing regulations and plant specification. The importance of regional variations in the specification and planning for capture ready plant has been identified after the issue was raised during the Global Carbon Capture and Storage Institute (GCCSI) roundtable workshop on CCS Ready in China in 2009.

The APECstudy in 2005 on storage capacity [5] assessed the potential of CO_2 storage in the Asia Pacific region. The results from their study show the northern part of China has a high prospectivity for storing CO_2 in the pink coloured sedimentary basins, which have many on-shore oil and gas fields. The western part of China has a low prospectivity for storing CO_2; however there is the possibility of enhancing gas recovery (EGR) in those regions. The southern part has a medium/unknown prospectivity to store CO_2 offshore in gas fields in the South China Sea. This is similar to the UK, where it is proposed to store CO_2 in the North Sea.

1.1. Carbon capture ready in Guangdong

Guangdong province, China is used as an example for this capture ready study. Guangdong is China's largest provincial economy; it has a higher GDP than Saudi Arabia and is the largest export manufacturing producer in China. It has also been proposed to be China's first CCS-ready province, starting with a study funded by the UK Foreign and Commonwealth Office (UK FCO), the British Embassy in Beijing, China and the British Consulate Guangzhou, China [6]. The aim is to provide initial work in a key province where CCS could be an integral part of China's low-carbon future. The aim of this project is to let government officers and local power plant owners become more aware of CCS technology and consider CCR in their decisions on new build power plants. If successful it would be a key step towards achieving a critical mass of commercial and political support for accelerated CCS deployment China- wide and internationally.

1.2. Background for CCS in Guangdong

Guangdong (highlighted in purple in Figure 1) is an ideal location to develop CCS related issues. The province is proud of its legacy of being at the forefront of economic development. Party Secretary Wang Yang has referred to the need to develop a low carbon economy in Guangdong, which provides a high-level momentum for policy makers drafting the provincial Climate Change Action Plan and the 5 year Energy Conservation Plan. Guangdong is also China's province with the lowest energy consumption per unit of GDP. This presents challenges to the provincial government, who need to continue to find new ways to hit enhanced targets to reduce their intensity levels. It is generally accepted that Guangdong will be using fossil fuels as its main energy source for the foreseeable future. Guangdong is thus well placed to see the value in piloting CCR deployment. The provincial government currently views CCS as an unproven technology but there is a growing academic and business community active in the province which is driving for the development of CCS and CCR options.

Figure 1Location of Guangdong Province in China

The capture ready study will start by investigating the existing power plants with high volume carbon dioxide emissions. It will then address the regional planning for carbon capture ready plant. In this study, only plants with over 300MW units, supplying electricity to the national grid, will be investigated. This is because only the most recently built, large size, advanced plants are likely to have FGD units fitted at the time of operation or might install FGD units in the future. Older and less efficient units face a big possibility of shutting down in the future, with extensive closures of such plants already having taken place as part of China's 'new for old' power plant replacement policy.

1.3. Existing power plant emissions

By the end of 2009, Guangdong had 30 coal-fired power plants with units of over 300MW installed capacity connected to the national grid. The total installed capacity for those plants is 22.04GW, which is about half of the total installed capacity for all fossil fuel plants in the province. Another 9 units located at four plants have obtained planning permission and will start operation in the next 2-3 years. **Error! Reference source not found.** shows the location of these plants in Guangdong. As some plants are built next to others but run by different operators, the dots shown in the figure are less than the real number. The average coal consumption in terms of standard coal is 323g/kWh, 9g lower than the national average [7], which has resulted from the wide implementation of newer, better performance generating units. Two plants do not have FGD installed at the moment. Two power plants started operation before the year 2000 and the majority started operation after 2003. The average unit operational hours per year in the province has dropped from 5,161 hours in 2006 to 4988 hours in 2007 [7], which is around 10% lower than the national average. Part of the reason is because of a lot of the small size oil power plants build in the 1990s are now used only during peak time. The power plants which are included in the study have average operational hours of 6,414 (73% load factor in average) hours per year (where information is available), with one plant operating at an extremely high 8059 (91% load factors in average) hours in 2008.

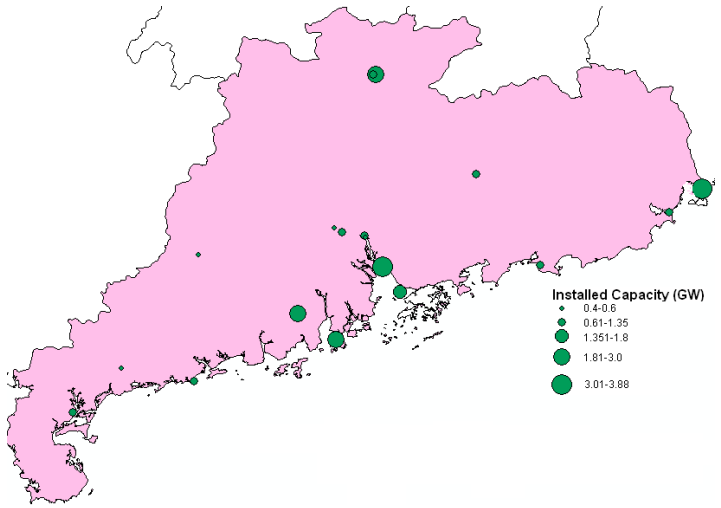

Figure 2 Power plants location with different installed capacity in Guangdong

Figure 2 shows the power plant generation capacity by size within Guangdong. It can be seen that the Pearl River delta region has the highest amount of carbon dioxide emissions within Guangdong. Shantou and Zhanjiang and Shaoguan are also identified as having comparatively high emissions. The Pearl River delta has the highest density of power plants within Guangdong.

1.4. Storage potential in Guangdong

Table 1 CO_2 storage potential in saline aquifer in Guangdong (Li 2009)

Basin name	Saline aquifer		Depleted oil field		Gas field	Total SC
	Size (km^2)	CO_2 SC	Increased oil production (MBO)	CO_2 SC	CO_2 SC	
Pearl River	83,028	68,700	89	41	12	68,753
Sanshui	3,000	1,260	2	1	N/A	1,261
Beibuwan	18,926	23,800	34	18	N/A	23,818
Total	104,954	93,760	125	60	12	93,832
SC: Storage capacity in Mt; MBO: Million Barrel						

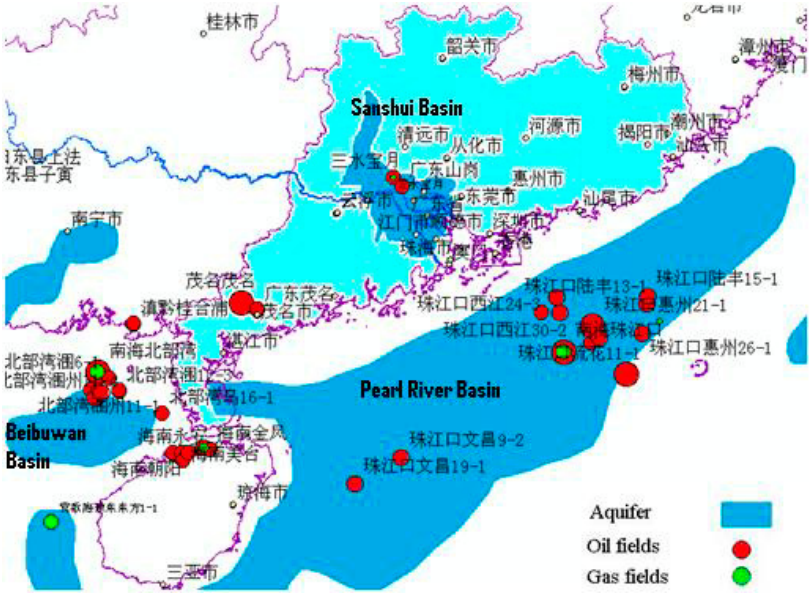

Figure 3 Potential storage sites in Guangdong (Li 2009)

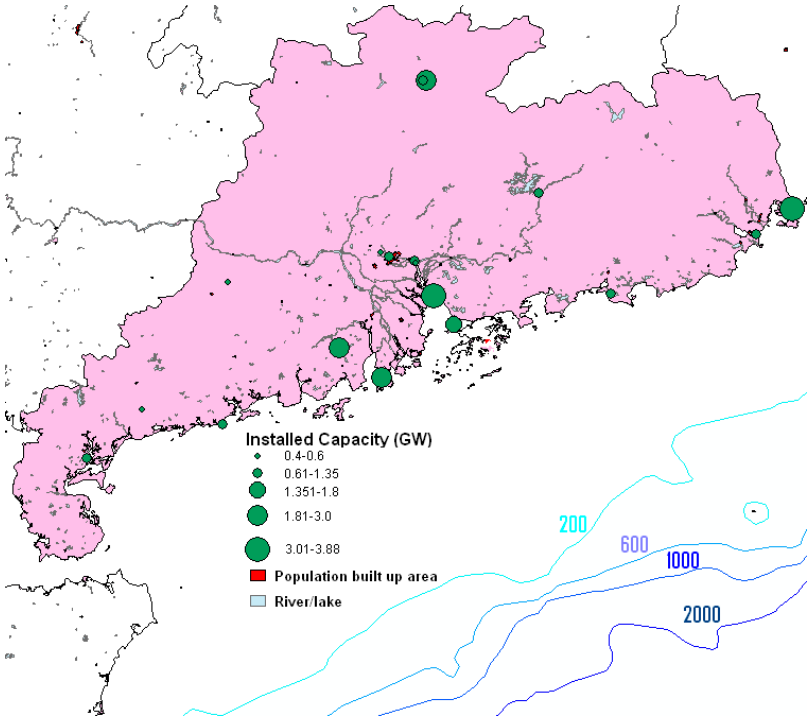

Figure 4 Depth of seabed (in metre)

According to a privately-commissioned study [8], the estimated carbon dioxide storage potential for Guangdong in saline aquifers, oil fields and gas fields is 93,760Mt, 60Mt and 12Mt respectively (see Table). This makes the total storage capacity of 93,832 Mt around the area, which is enough for 781 power plants with 1GW installed capacity to store all of the carbon dioxide emission during their 30 years operational life. This storage capacity is big enough to store all of the current emissions of China's coal-fired power plant. However, most of the storage opportunities are offshore in saline aquifers, making the operation and construction cost of pipeline and injection facility more expensive than the onshore option (See Figure 33 for site location). The onshore storage opportunity is 1,261Mt at the Sanshui basin, which is enough for storing all the carbon dioxide emitted from the units investigated in this study for 10 years.

Compared with the limited storage capacity onshore, offshore storage in saline aquifers shows a promising future for carbon capture and storage in Guangdong. Over 98% of the potential storage sites are offshore and within the easy reach of the coast. The southern part of the Pearl River basin is around 200m in depth as shown in Figure 4. The long term large scale storage of carbon dioxide is likely to be in saline aquifers offshore, roughly within 150 km of the coastline. For power plant built next to the coast line, the cost benefit will be bigger. In addition, such new power plant can avoid residential areas and can use sea water cooling, which is common practice in coastal power plants.

Site selection, might also be influenced and simplified by the concept of industrial development clusters. Examples of such clusters would be power plants, chemical industries and wind farm manufacturing facilities to be built in the Zhangjiang area, the new power plant in planning in the Shantou area etc. Both areas are close to storage sites and already have large carbon emissions. Therefore, three clusters are identified in the study as shown in Figure 5.

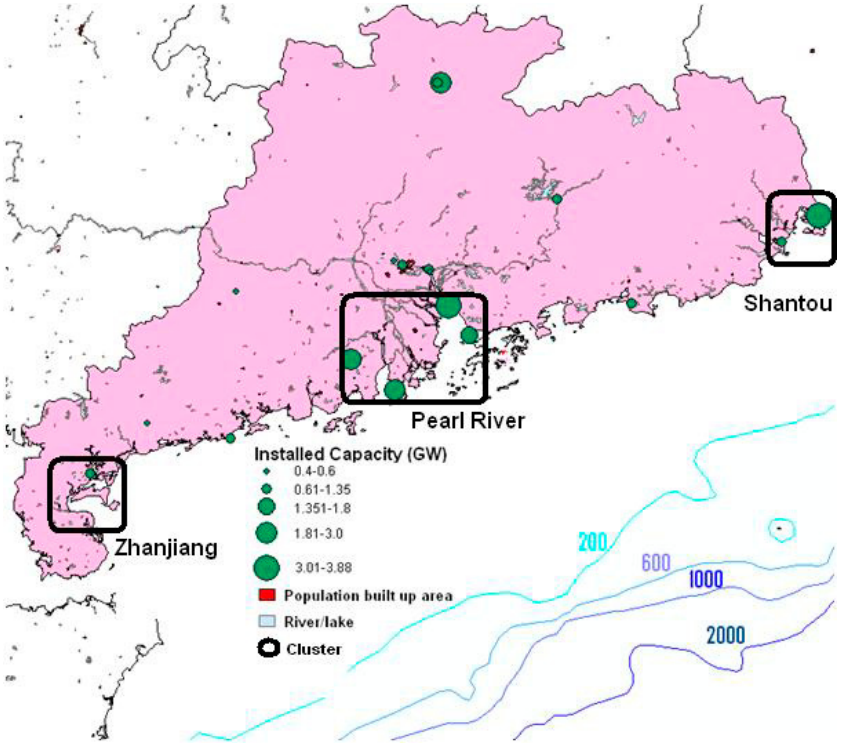

Figure 5 Potential CCS clusters in Guangdong

The biggest cluster, the Pearl River cluster, has a higher installed capacity of around 15GW, compared to the clusters in Shantou and Zhanjiang, which currently have 5GW and 1.2GW installed capacity respectively. However, because of the economic development imbalance in previous years, Shantou has in recent years proposed more new power plants than elsewhere in Guangdong. The two main limitations of the cluster plan are:

A) The region can extend to a larger area, including the Bebuwan basin in Guangxi province and another large emission area in Fujian Province. Hong Kong, which is to the south of the Pearl River, hosts one of the world's largest power plants and could also be included.

B) Small scale power plants not connected to the national grid can be considered in future study. There are currently 162 units with a total installed capacity of 3.07GW. The biggest unit has a capacity of 350MW while the smallest unit is only 0.8MW [9]. Because it does not supply electricity to the national grid, neither the policy of the closing down small, inefficient power plant, nor SO_2 emission limitations, apply

When considering the regional extent, multi-province evaluations are better than only considering a single province in isolation. As can be observed, the Zhanjiang and Shantou clusters are both located close to the bounder of Guangdong Province. Both Guangxi province and Fujian province are expected to have fast economic growth within the next ten to twenty years as labour and operational costs in Guangdong are getter higher and Guangdong province is seeking opportunities to transform its economy to high value industries rather than manufacturing.

The large number of small installed units in Guangdong has created great difficulty in the cluster planning. Since the plants do not rely on selling electricity to the national grid as their only income they are difficult to regulate by means of most of the existing environment laws. Even if a company is prepared voluntarily to cut its emissions, there remain concerns over potential bankruptcy or the effect on the company's valuation by a third party. Finally, connecting pipelines to small units might not be seen as priority compared to other emission sources. Therefore, the inclusion of

small plants should not be considered as reasonable direction of investigation unless large scale retrofit happens first.

The geographical location of Guangdong provides it with the opportunity to access energy sources by shipping rather than rail. Most of the coal burned in coastal areas in China is from Australia, while the inland areas largely rely on coal produced in Shanxi province or Inner Mongolia. The same principle can apply to the storage clusters. The cluster does not need to occupy any existing industrial land; it could be built on an island, which is similar to the concept of the existing power plants and LNG terminals in the region. This can save the cost of land purchase while avoiding the populated areas.

2. Conclusion

Regional planning is a priority if capture ready is going to happen within the next 10 years. The concept of "region" should not be limited to a single province or country, but could include places with similar energy resources, linked electricity generating systems, and, most importantly, sharing the same storage infrastructure for CCS. In this study, examples were given in order to gain a better understanding of how clusters should be planned and created. The real challenge in planning for CCR lies in the quantity and quality of data available for a specified region, the scope for coordination beyond political borders and understanding the future development planning. Making a region carbon capture ready is not just a technical or engineering problem; it depends on planning, policy and economic issues as well.

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